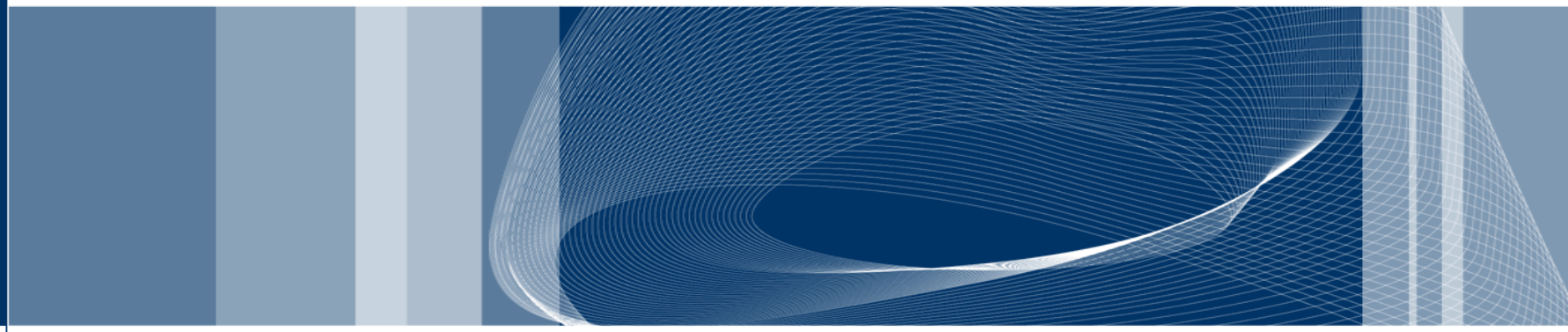
POLITECNICO DI MILANO

Workshop on «Computational Fluid Dynamics»
Czech Technical University in Prague, June 12-13, 2019



Some best practices in applied CFD

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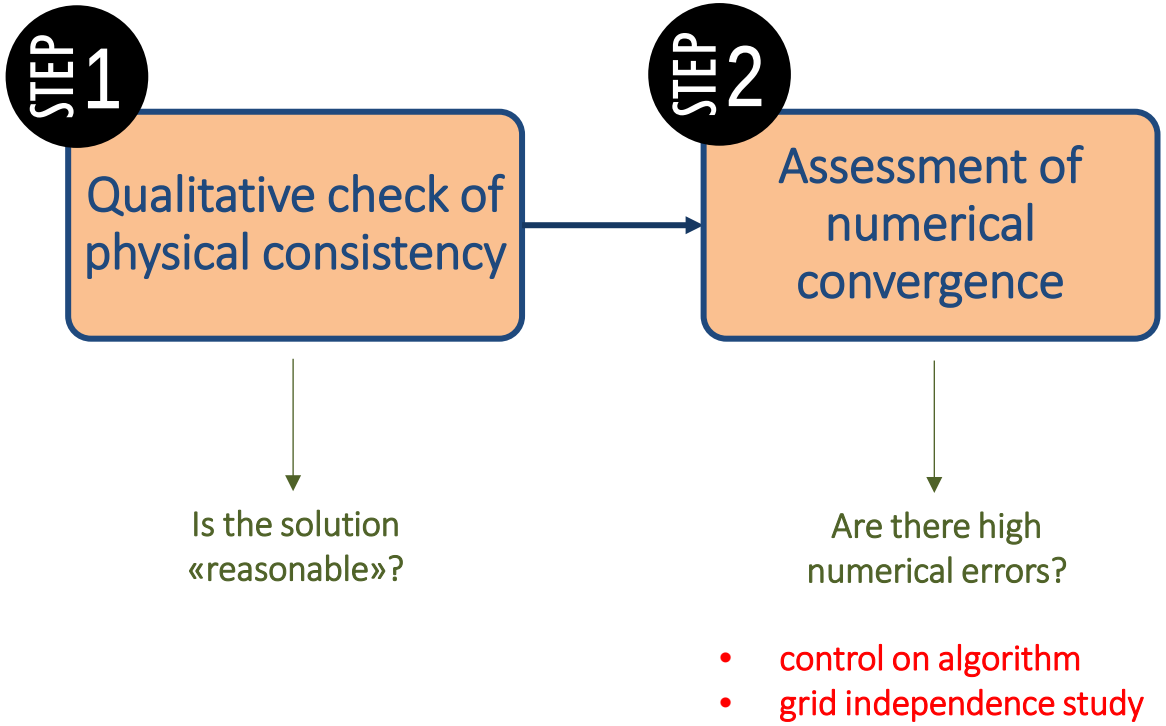
Best practices in applied CFD

Workflow



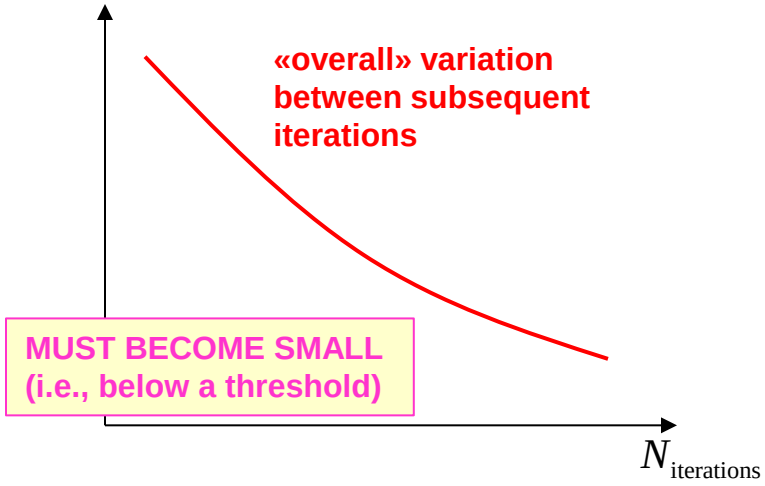
Assessment of numerical convergence

Control of iterative algorithm

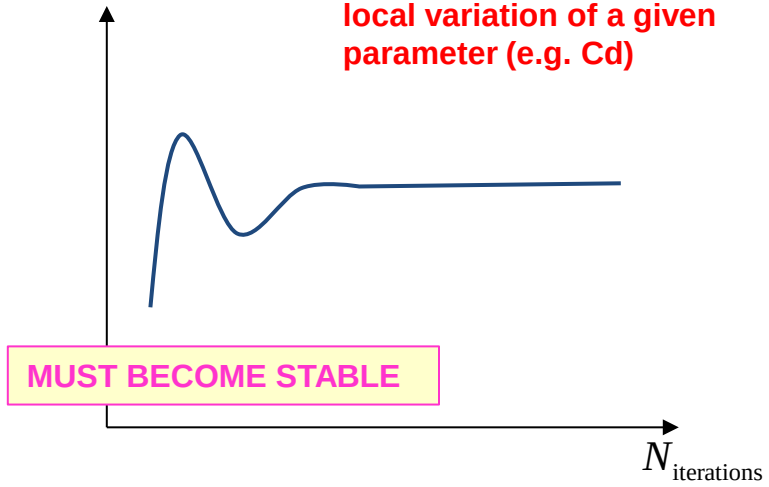
The solution of the discretized equations is performed in an **iterative way**

How can I guarantee that the solution is converged?

Whole-field residuals



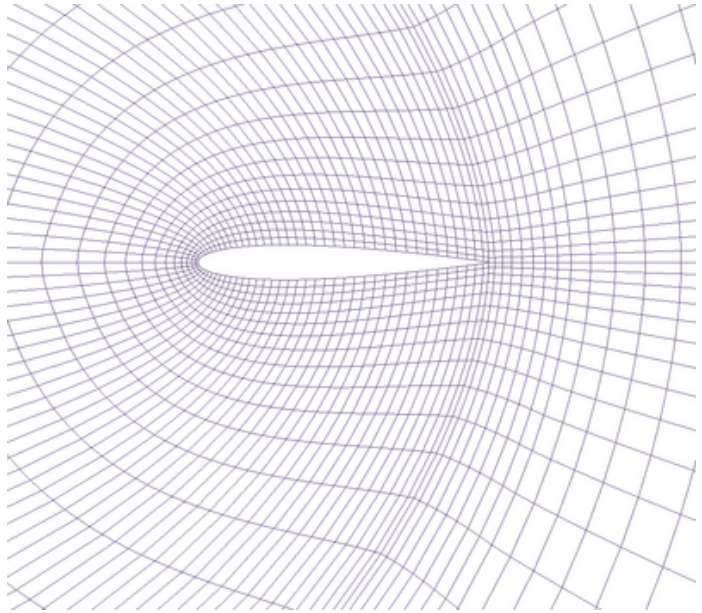
Target parameters



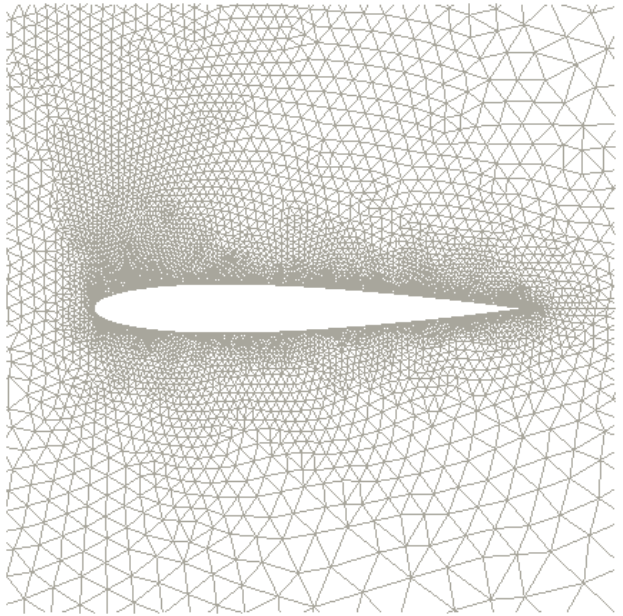
Assessment of numerical convergence

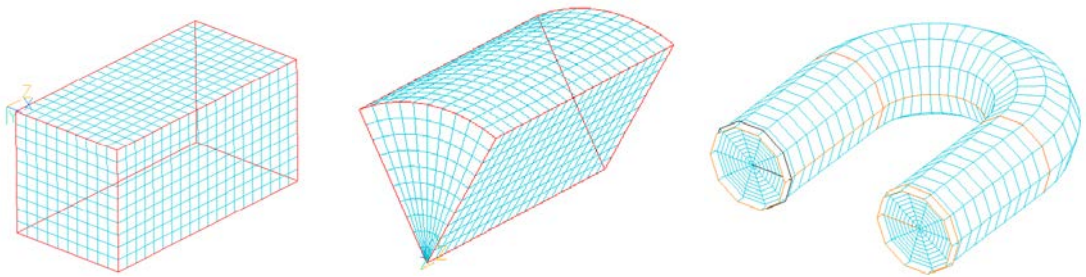
Types of meshes

Structured mesh



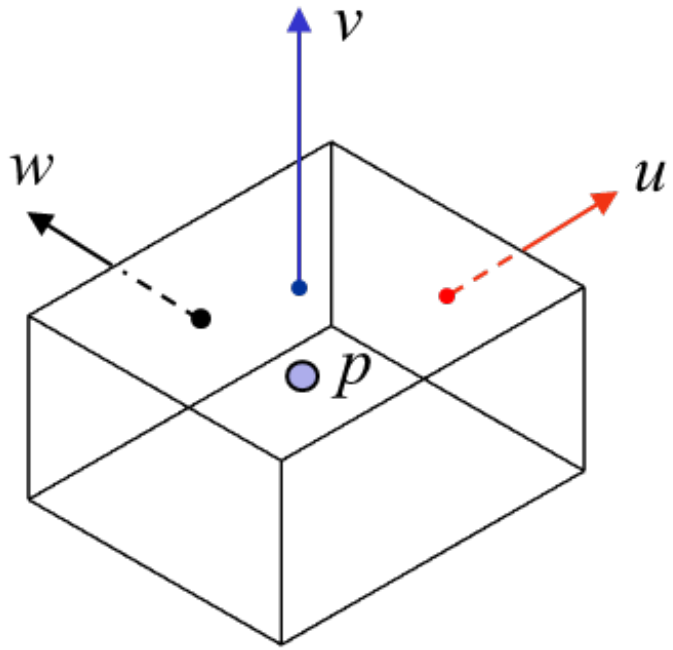
Unstructured mesh



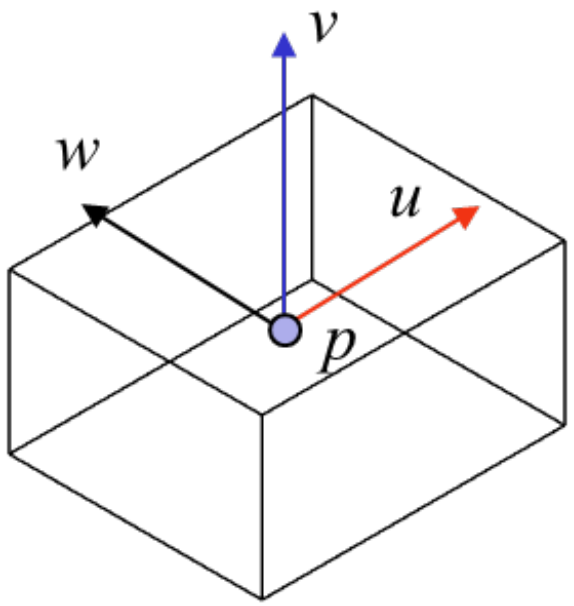


Assessment of numerical convergence

Staggered grid arrangement



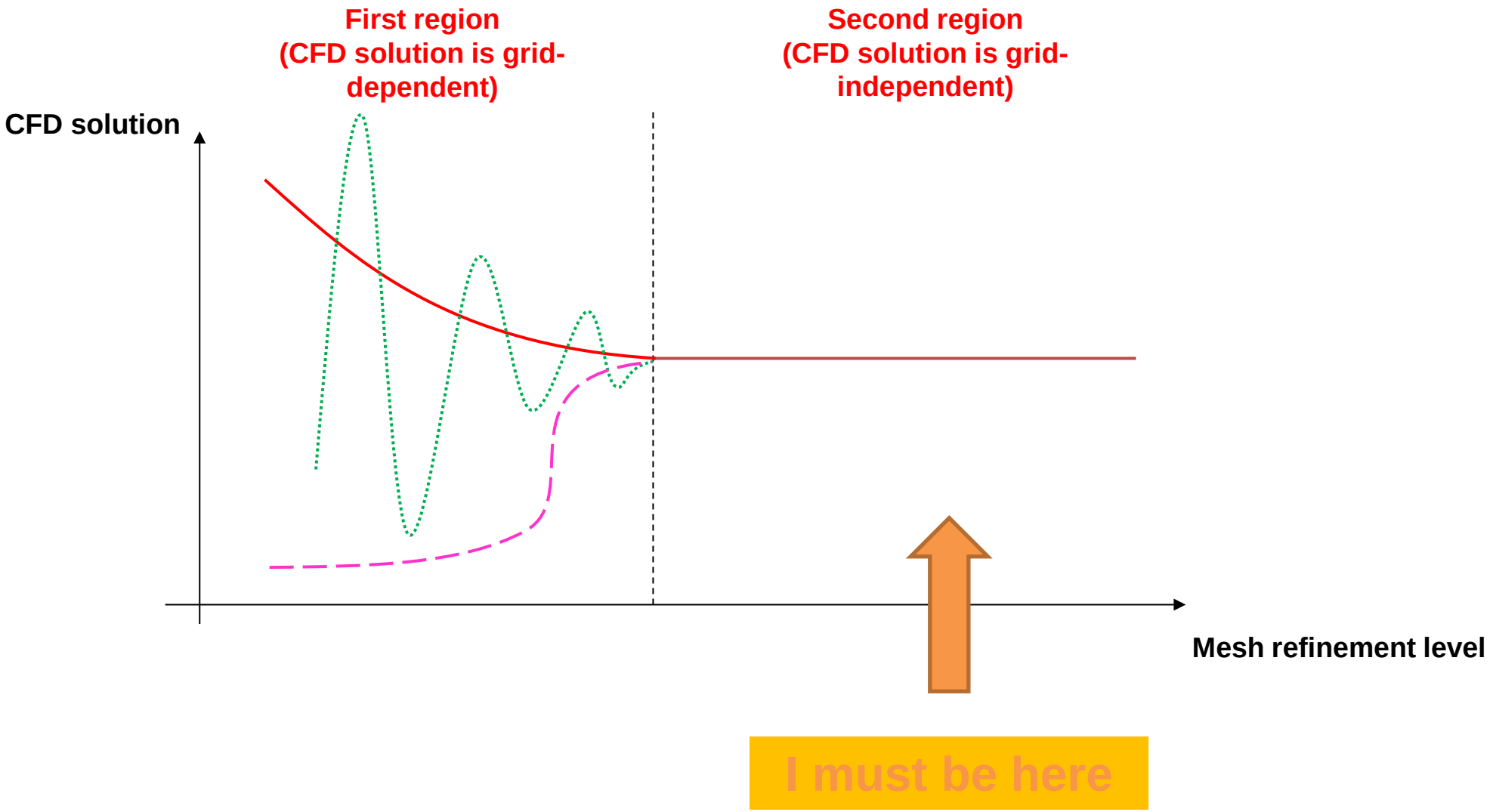
Staggered grid arrangement



Co-located grid arrangement

Assessment of numerical convergence

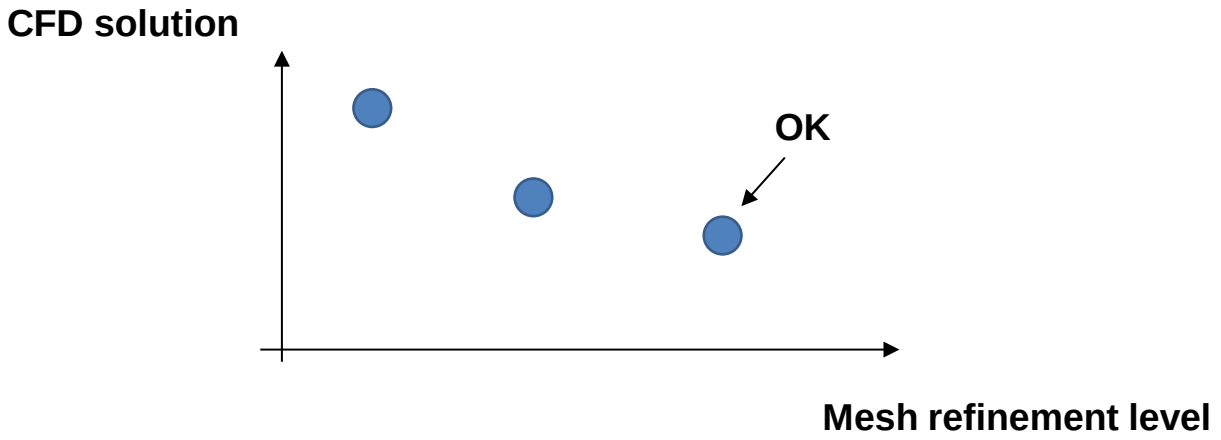
Grid independence study

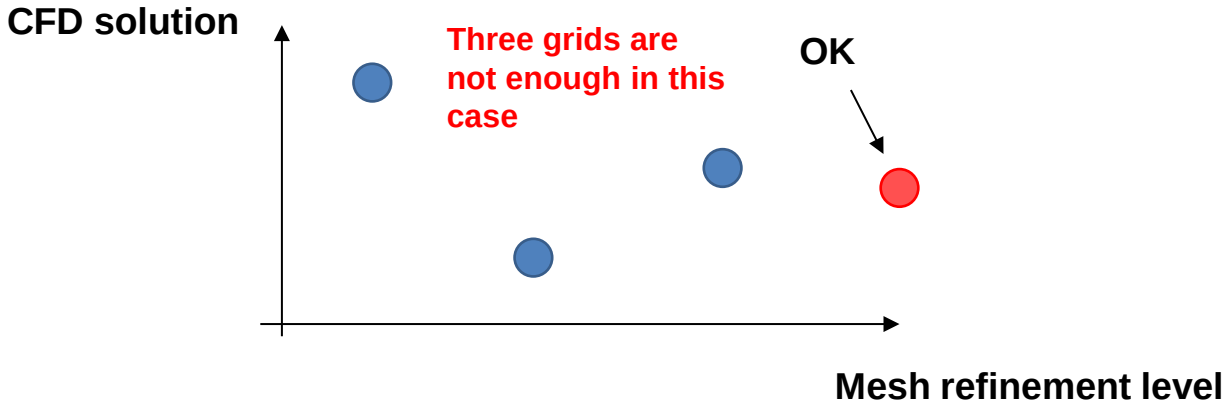


Assessment of numerical convergence

Grid independence study

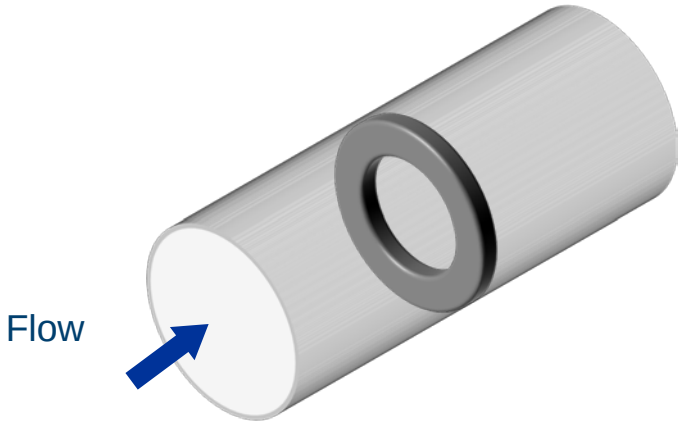
- Run several simulations increasing the mesh refinement level (number of cells?) and try to identify the 2 two regions. In practice, **at least 3 grids** are required.
- I stop when the finest mesh is **in the second region**.
- **But what is f?** Basically, f is the parameter I want to estimate through the numerical simulation (e.g., the pressure drop, the drag coefficient…)
- In principle, the verification of the grid independence of a given f does not extend to **other features of the solution.**

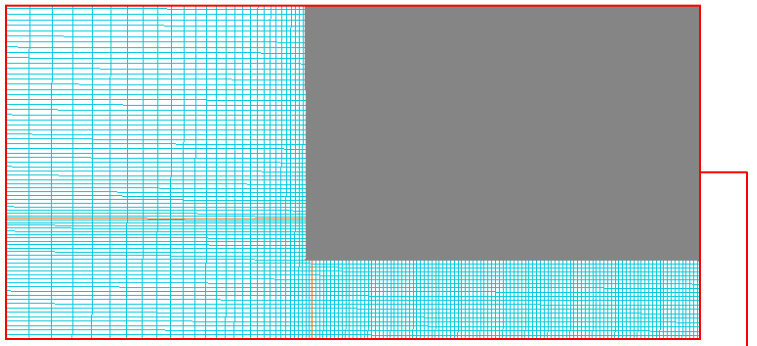


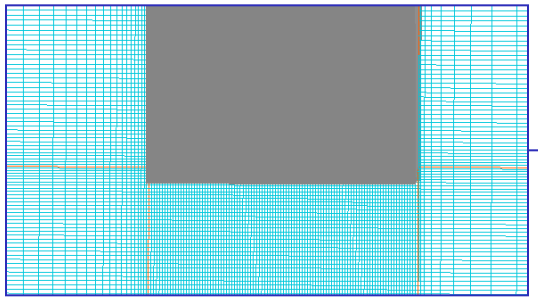


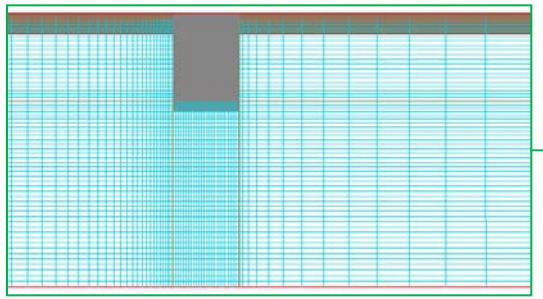
Assessment of numerical convergence

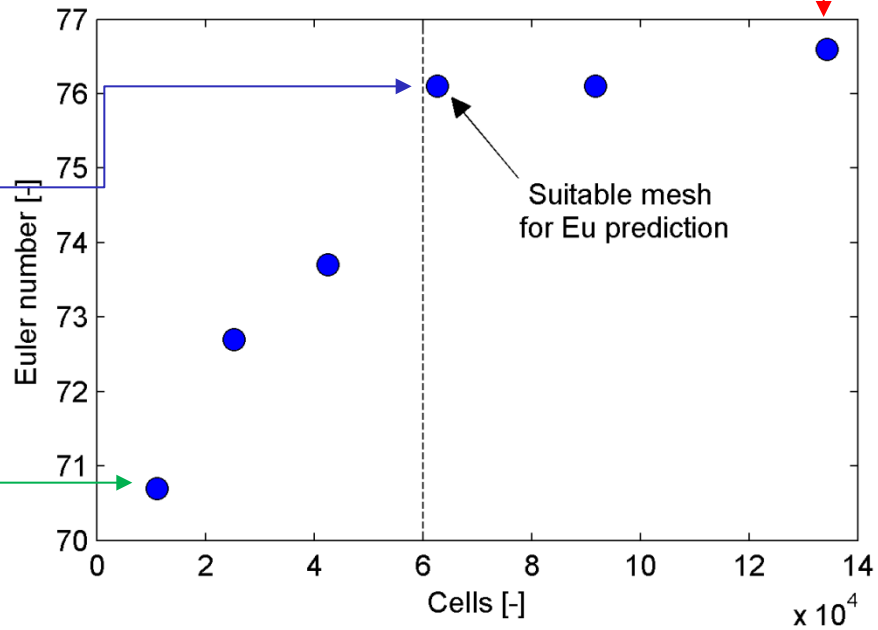
An example of grid independence study









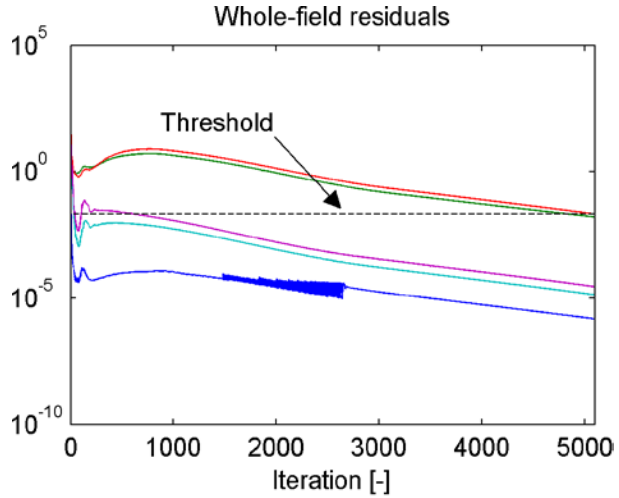


Assessment of numerical convergence

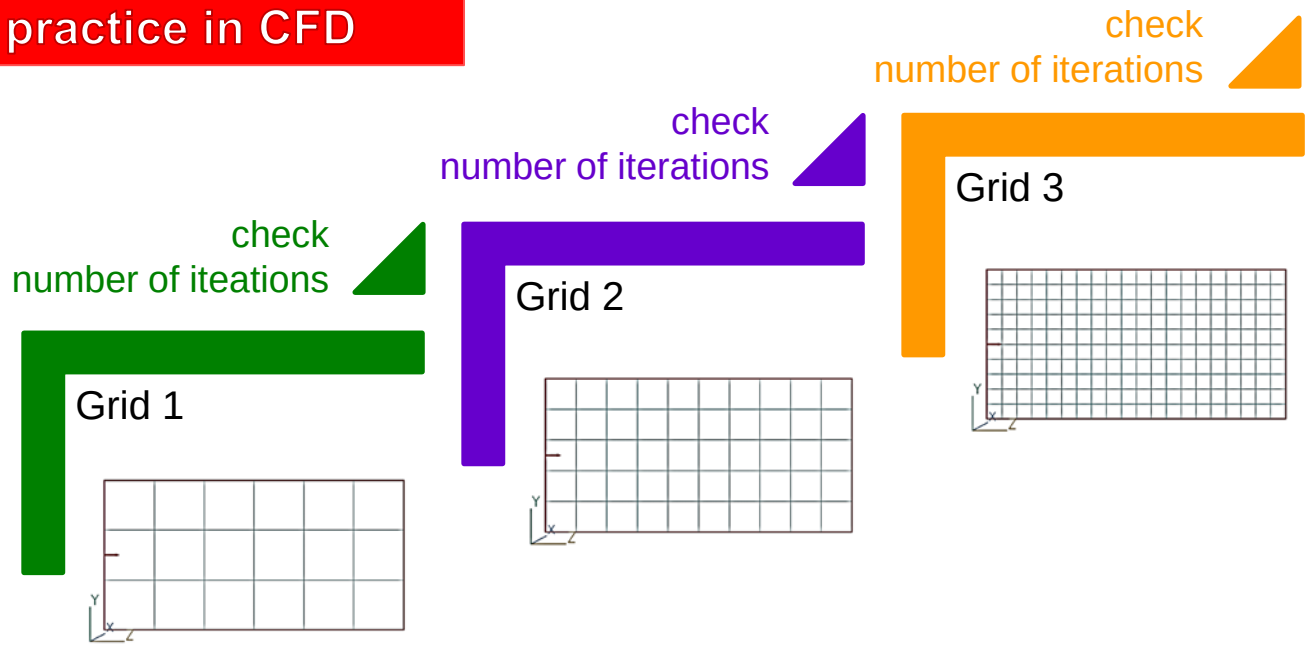
Best practice

It is clear that, for each simulation, the attainment of convergence with respect to the **number of iterations** must be verified.

The number of iterations requried to reach convergence increases with the **grid refinement level.**

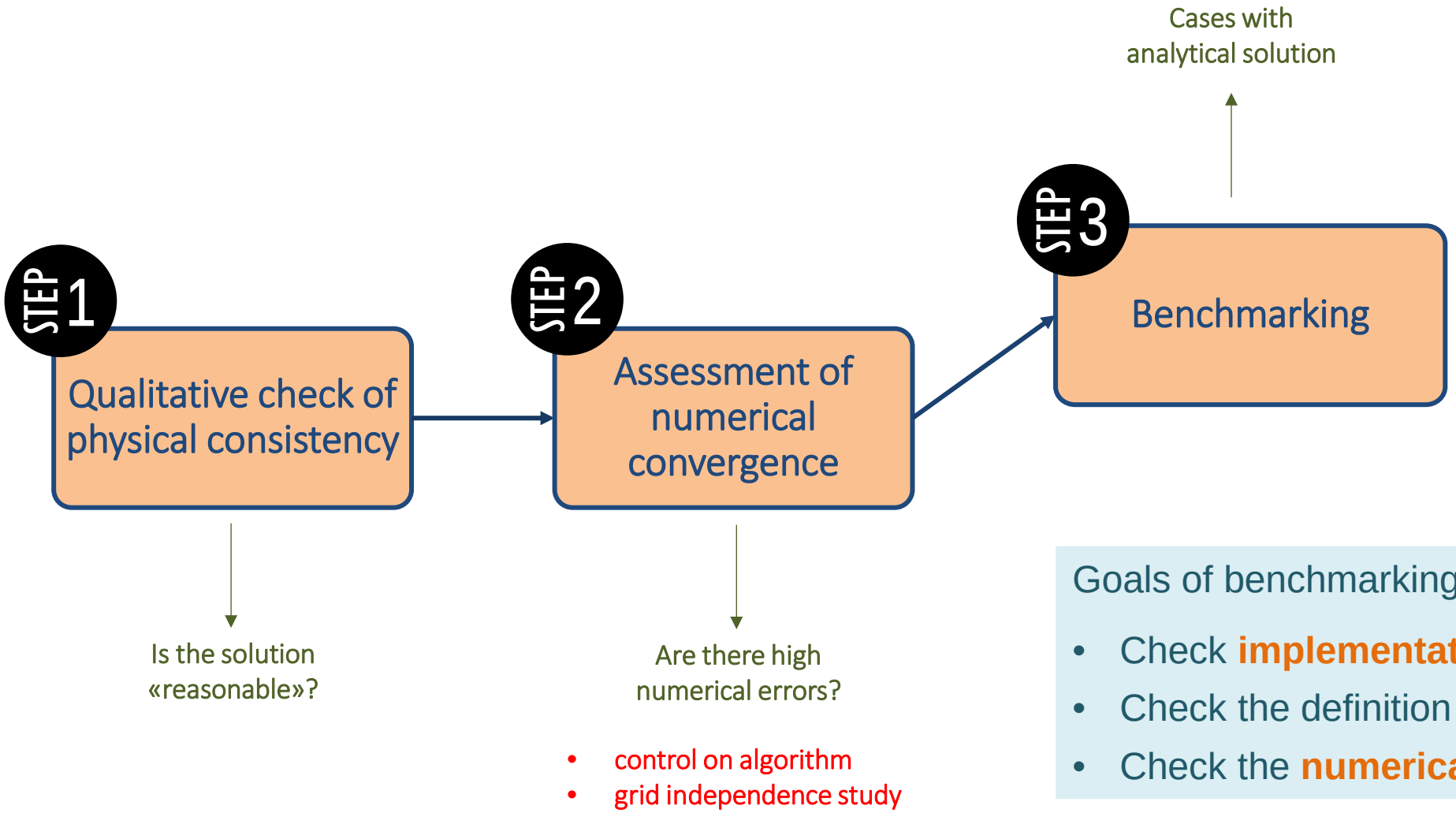


Best practice in CFD



Best practices in applied CFD

Workflow

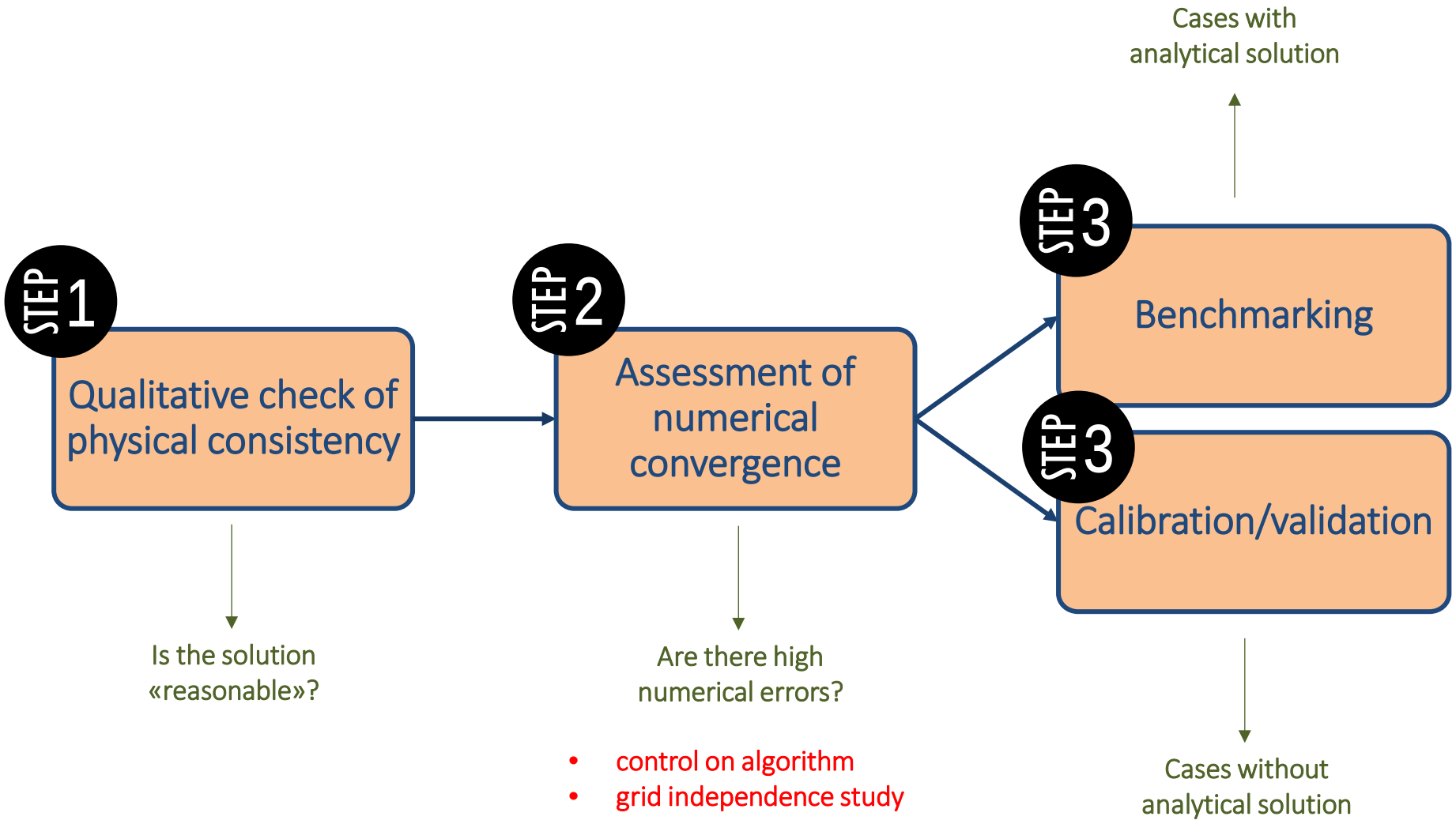


Goals of benchmarking:

- Check **implementation** of in-house code
- Check the definition of the **CFD set up**
- Check the **numerical error**

Best practices in applied CFD

Workflow



Calibration/validation

Sources of uncertainty in CFD simulations

	Numerical sources of uncertainty	Modelling sources of uncertainty
Why?	The flow equations are **solved numerically** (e.g. FVM)	The flow equations are **manipulated** before being solved numerically (e.g. RANS from NS)
What?	Solution algorithms Differencing schemes Convergence criteria Spatial discretization (mesh) Time step settings …	Turbulence model … … … … …
How?	Controlled through a convergence study	Controlled through: - theoretical considerations - guidelines from literature - calibration/validation

Calibration/validation

Scope of calibration/validation

decide the **modelling factors** (e.g. the turbulence model) by comparison against external data, which can be:

- experimental data (more frequently)
- other numerical data (less frequently)

Calibration

select the **best** among different options.

e.g. which turbulence model works best for my case?

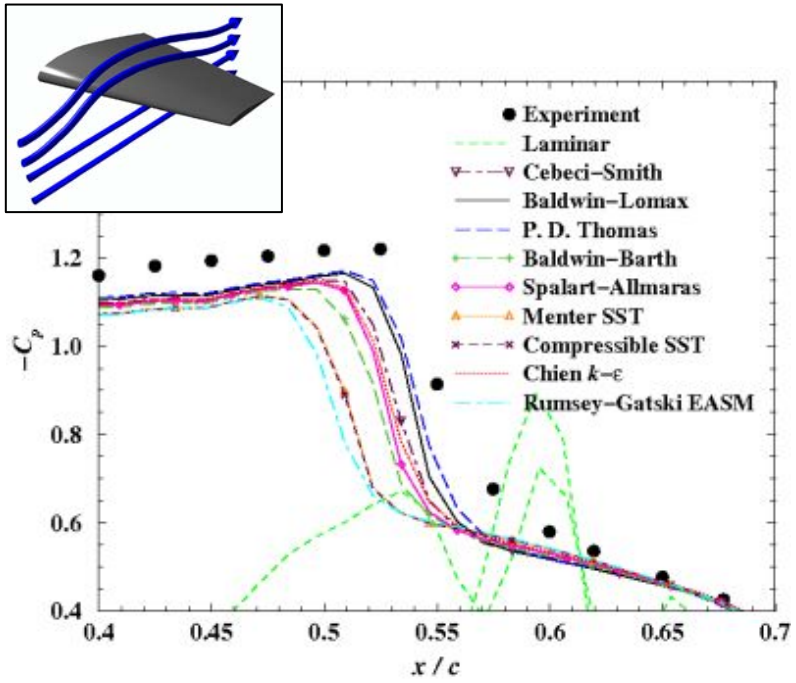
Validation

check the suitability of a **given option**

e.g. does the k-ε standard model work well for my case?

Note

- often performed **sequentially** (validation after calibration)
- sometimes performed **together** (on a large database)



http://www.innovative-cfd.com/turbulence-model-2.html

Calibraton/validation

Comparing CFD results with other (experimental) data

Guidelines & challenging yet relevant questions

- never forget to account for the **uncertainty** of CFD and exp. results
- if possible, always add the **uncertainty bars**

CFD

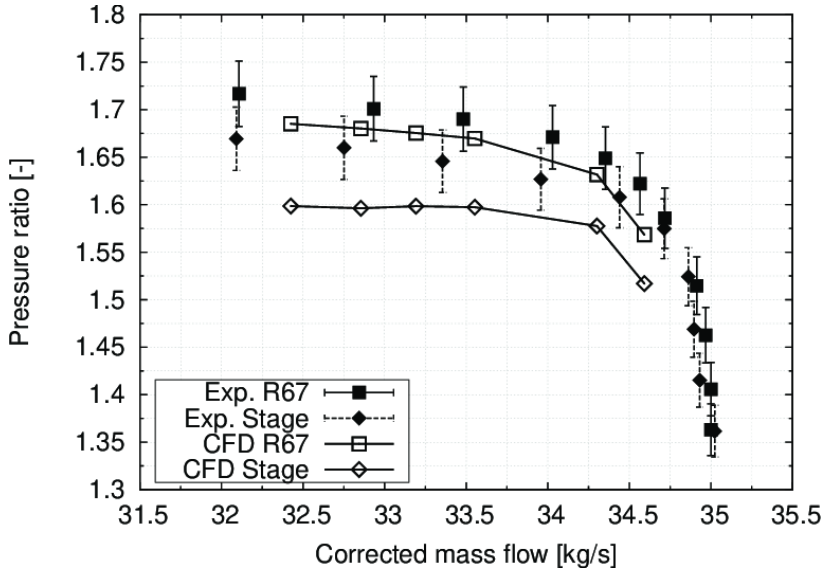
where do the **uncertainty bars of your CFD solution** come from?

- how can you quantify or reduce them?
- how can I improve the CFD solution accuracy?

EXP

where do the **uncertainty bars of experimental data** come from?

- if you are running yourself the experiment, how can you quantify or reduce the bars?
- If you are taking the data from the literature, are the uncertainty bars provided?
- Is there any mismatch between what I am simulating and what has been tested?



Pardo et al. (2014)

Useful suggestions

- when taking experimental data or formulas from the literature, always try to read the **original references**
- never trust the literature information (but also your CFD results): none of them is **an ABSOLUTE TRUTH!**

Best practices in applied CFD

Workflow